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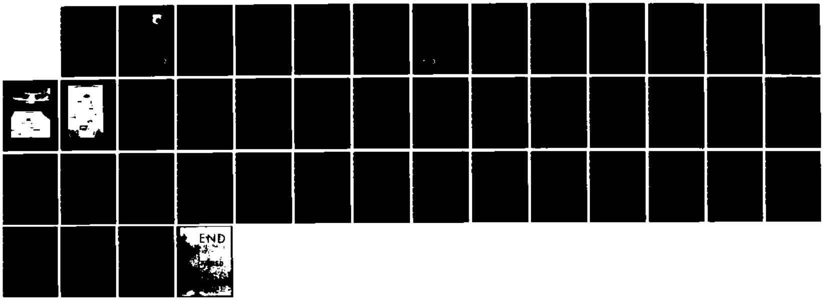

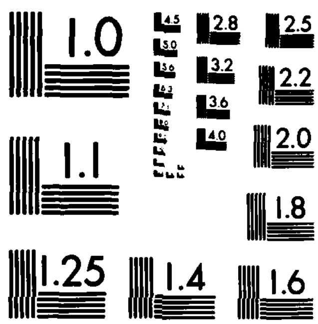

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A PRELIMINARY FLIGHT EVALUATION OF THE PERIPHERAL VISION DISPLAY USING THE NT-33A AIRCRAFT

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March 1984

Final Report for Period October 1982 to December 1983.

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This technical report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Malcolm Horizon, a Peripheral Vision Display (PVD), was installed in the NT-33A variable stability research aircraft. The display provided the evaluation pilot with a gyro stabilized horizon line of red laser light. An experiment was conducted to determine the effect of the PVD on pilot workload. Workload was inferred from performance on a secondary task, in this case, the Sternberg task generated by the Workload Assessment Device (WAD). The primary piloting task required maintenance of airspeed, altitude, and angle of bank during instrument flight conditions. Nine NT-33A flights were flown by two evaluation pilots. Presence of the PVD reduced the WAD reaction times of one of the pilots. The reaction times of the other pilot showed mixed results. In-flight data and the pilots' subjective comments about the display are discussed.

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FOREWORD

The report was prepared for the United States Air Force by Calspan Corporation, Buffalo, New York, in partial fulfillment of USAF Contract Number F33615-79-C-3618, Airborne Simulation and Research Investigations, NT-33A Task 10. Funding for the study was provided by the Flight Dynamics Laboratory, the U.S. Air Force Test Pilot School, and the Canadian National Defense Headquarters.

Mr. Jack Barry, Mr. Bill Augustine, and Captain Mike Maroney, USAF of the Flight Dynamics Laboratory deserve recognition for their support of the program. Mr. Art Kennedy of Garrett Manufacturing Limited provided assistance in coordinating maintenance support for the Peripheral Vision Display. Mr. John Buechele of SRL, and Petty Officer Peter Theune of the Naval Air Test Center operated the Workload Assessment Device. Funding for the Workload Assessment Device support for this experiment was provided by the Naval Air Development Center.

We are grateful for the dedicated efforts of the two pilots from the Air Force Test Pilot School who performed the evaluations described in this report. The chase aircraft and crews provided by the U.S. Air Force Test Pilot School for the flights at Edward AFB, and by the Canadian Forces for the Buffalo flights were very effective in ensuring that the NT-33A flights were conducted safely. In addition, Captain A. Lamoureux, from the Canadian National Defense Headquarters was very helpful in guiding the initial flight checkout of the PVD as well as the experiment design.

Successful completion of this flight program was possible through the individual efforts of many members of the Calspan Flight Research Department. Messrs. Chuck Berthe and Mike Parrag served as Safety Pilots in the NT-33A. Messrs. William Palmer and James Cornwell served as NT-33A crewchiefs. Mr. Ron Huber supervised the installation and electronic interfaces of the display with the NT-33A, while Mr. Tom Franclemont maintained the aircraft systems in the field.

Finally, the contribution of Dr. Sam Schiflett to the experiment design and interpretation of the results is greatly appreciated.

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LIST OF SYMBOLS AND ABBREVIATIONS

FAM	Familiarization Flight
HUD	Head-Up Display
IMC	Instrument Meteorological Conditions
ISI	Inter-stimulus Interval
LCD	Liquid Crystal Display
MSET	Memory Set
PVD	Peripheral Vision Display
VMC	Visual Meteorological Conditions
VSS	Variable Stability System
WAD	Workload Assessment Device
ζ_{DR}	Dutch-roll Damping Ratio
σ	Standard Deviation
τ_R	Roll Mode Time Constant
ϕ_e	Roll Angle Error
$\lvert\phi/\beta\rvert$	Absolute Value of Roll-to-Sideslip Ratio
ω_{DR}	Dutch-roll Undamped Natural Frequency

Section 1
INTRODUCTION

The Peripheral Vision Display (PVD), or Malcolm Horizon, is a device which projects a thin line of laser light representing the real horizon onto an aircraft's instrument panel. The horizon line is gyro stabilized and moves in pitch and roll in the same manner as outside visual cues. Normally a pilot gains his aircraft attitude awareness using peripheral cues during visual meteorological conditions (VMC), but must rely on a focused scan of flight instruments during instrument meteorological conditions (IMC). The advantage of the Malcolm Horizon is that a pilot can use his peripheral vision rather than foveal vision to determine his aircraft's attitude, freeing his foveal vision for use on other tasks. In addition, the pervasive peripheral cuing provided by the PVD may reduce the risk of disorientation. If the PVD proves to be an effective cuing device, it would reduce the pilot's mental workload, allow a pilot to direct more attention to aircraft systems operation during IMC, and reduce the occurrence of pilot vertigo.

A Stage B Model of the PVD was installed in the USAF NT-33A research aircraft during late 1982. In early 1983, an experiment was conducted using the NT-33A variable stability system and the Workload Assessment Device to determine if, in fact, the PVD did reduce pilot workload. The experiment was refined during several NT-33A flights at Buffalo, NY in February. The data collection flights discussed in this report were flown in March 1983 at Edwards AFB, CA.

This report includes a description of the experiment design, test equipment and test procedures, an analysis of the flight data, and a summary of findings.

Section II
EXPERIMENT DESIGN

1. OVERVIEW

The experiment described in this report was a preliminary evaluation of the PVD's ability to reduce pilot workload during instrument flight conditions when the pilot must perform a secondary but mission critical task such as operating a navigation or weapon system. In this situation it was hypothesized that the pilot could maintain his attitude awareness much as he does during visual flight conditions by using peripheral cues derived from the PVD. If the pilot could utilize the PVD in this manner, he could refer less frequently to his flight instruments and devote more attention to secondary cockpit tasks.

During the experiment the evaluation pilot's primary task consisted of flying an angle of bank profile at constant altitude and airspeed under simulated instrument conditions. His secondary task consisted of a Sternberg task (Reference 1) which required him to respond to various letter sets presented on a visual display located well away from the aircraft's flight instruments. These tasks were performed under two conditions - with the PVD on, and with the device turned off. Data were collected concerning the pilot's precision in performing the instrument maneuvering task and his performance on the Sternberg task. The following sections describe each aspect of the experimental design in greater detail.

2. NT-33A AIRCRAFT

The test aircraft was the USAF NT-33A in-flight simulator (Figure 1) operated by Calspan under contract to the Flight Dynamics Laboratory. The NT-33A variable stability system (VSS) uses a response feedback technique to generate a wide range of aircraft static and dynamic characteristics. The front cockpit of the NT-33A contains the variable feel, fly-by-wire set of flight controls which are flown by the evaluation pilot (Reference 2). The rear cockpit of the NT-33A containing the original T-33 mechanical flight control system, is occupied by the Calspan safety pilot.

On this program the VSS was programmed to provide good handling qualities in the longitudinal axis. The lateral and directional axes were adjusted to provide a lightly damped Dutch roll mode with a high roll-to-yaw ratio. This set of Dutch roll characteristics required the pilot to devote a significant portion of his attention to control angle of bank.

The VSS feedback gains needed to provide the aircraft dynamics were varied with aircraft fuel load in order to keep aircraft response constant as the NT-33A's moments of inertia changed with fuel consumed. Aircraft calibration records were taken in flight at several different fuel loads to ensure that the aircraft dynamics remained constant. The calibrations provided the dynamic characteristics shown in Table I. The variations in modal response with fuel shown in Table 1 did not noticeably alter the pilot's task.

Table I

NT-33A LATERAL DIRECTIONAL MODAL RESPONSES AS A FUNCTION OF FUEL LOAD

Fuel Remaining	LAT/DIR Characteristics
600 gallons	ω_{DR} = 1.6 r/s ζ_{DR} = 0.12 $\lvert\phi/\beta\rvert$ = 2.6 τ_r = 0.5s
500 gallons	ω_{DR} = 1.8 r/s ζ_{DR} = 0.11 ϕ/β = 2.8 τ_r = 0.5s
400 gallons	ω_{DR} = 2.0 r/s ζ_{DR} = 0.08 $\lvert\phi/\beta\rvert$ = 2.7 τ_r = 0.45s

To make the pilot's control of aircraft attitude more demanding, random disturbance signals were input into all three aircraft control axes. Three independent disturbance generators provided random disturbance signals which were filtered by second order low pass filters and then forwarded to the NT-33A rudder, aileron, and elevator input channels. The break points for these shaping filters were set at 0.3 Hz for the aileron and rudder, and 0.7 Hz for the elevator. The mean amplitude of the disturbances was set by potentiometers in the safety pilot's cockpit. Since the effectiveness of the disturbances on aircraft angular accelerations varied as the NT-33's moments of inertia changed with fuel load, the disturbance amplitudes were scaled according to aircraft fuel remaining.

To simulate instrument flight conditions for the evaluation pilot, a hood was manufactured for the front cockpit of the NT-33A. This hood consisted of three opaque rigid panels which covered the front windshield. In addition, an opaque flexible plastic covering enclosed the front cockpit canopy. This vision restriction equipment was stored in the front cockpit so that it could be installed by the evaluation pilot after takeoff and removed prior to landing.

The front cockpit primary attitude indicator consisted of a 5 inch Lear Siegler ARU 2B/A attitude gyro. The Head-Up Display (HUD) normally installed in the front cockpit was removed for this study. The layout of the NT-33A's front cockpit instruments is shown in Figure 2.

3. WORKLOAD ASSESSMENT DEVICE

The Sternberg task, which constituted the evaluation pilot's secondary task, was generated by the Workload Assessment Device (WAD). This pilot workload measurement tool was developed by Systems Research Laboratories, Inc. (SRL) for the Systems Engineering Test Directorate of the Naval Air Test Center (NATC). The device consists of a processor and recording system located in the nose of the aircraft, a display system in the front cockpit, and a control terminal in the rear cockpit. The processor generated a random sequence of letters which were presented to the evaluation pilot on a small Liquid Crystal Display (LCD) located on the lower front instrument panel (Figure 3). The WAD display was placed in a position that required the pilot to look away from

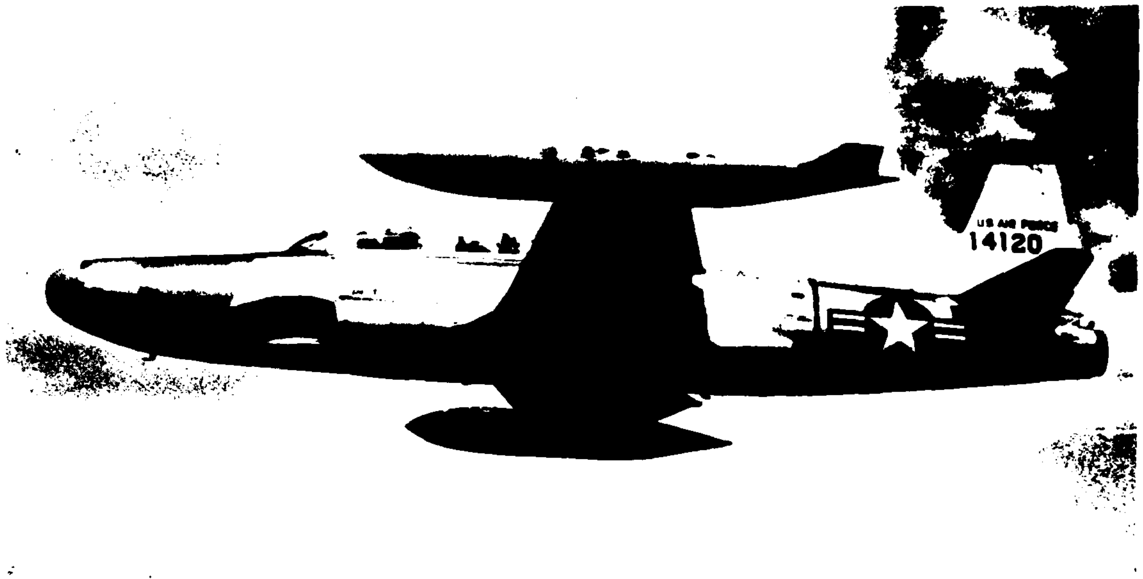

Figure 1 USAF NT-33A RESEARCH AIRCRAFT

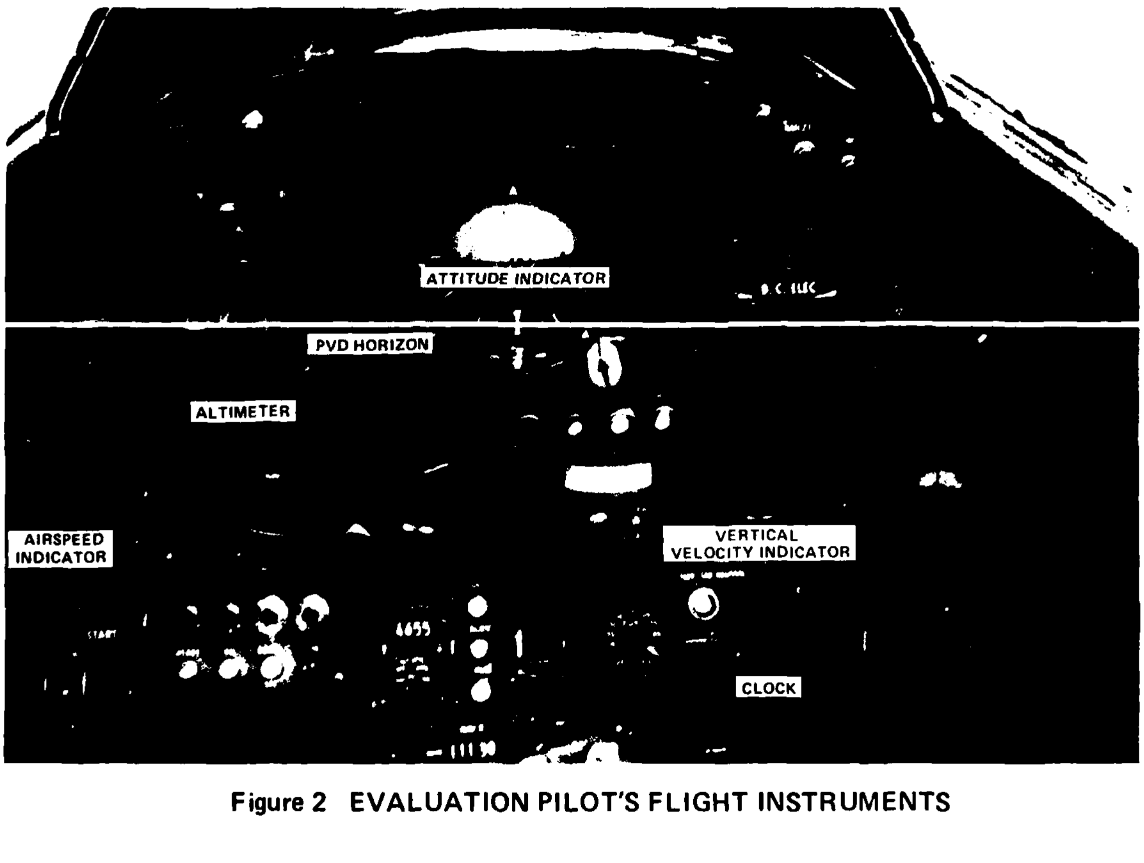

Figure 2 EVALUATION PILOT'S FLIGHT INSTRUMENTS

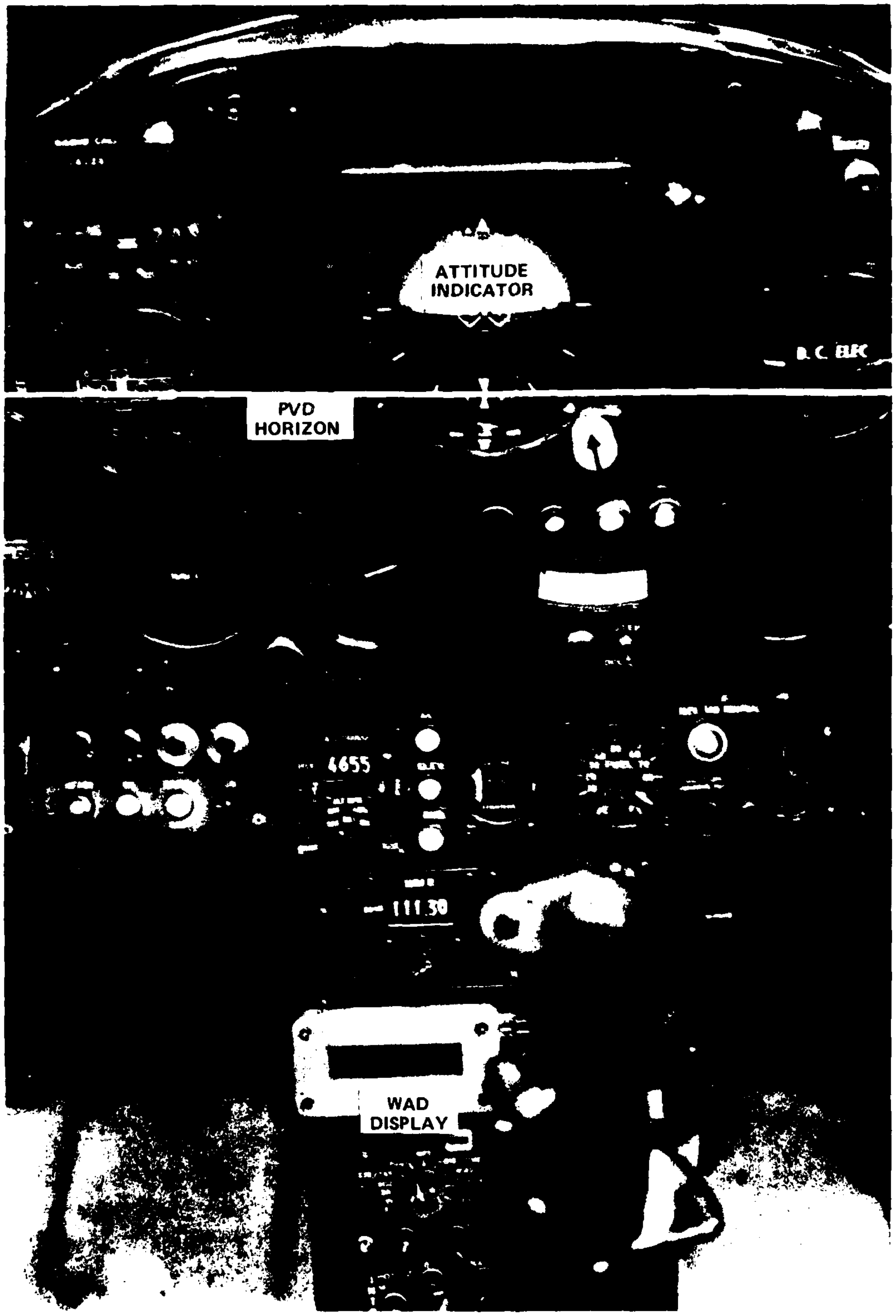

Figure 3 EVALUATION PILOT'S COCKPIT SHOWING LOCATION OF WAD DISPLAY

his flight instruments in order to see the WAD letters. The WAD system was controlled by the rear cockpit safely pilot by means of a keyboard terminal mounted on the left instrument panel.

During a workload test, the WAD presented one letter at a time to the evaluation pilot at a random interval of 3 to 7 seconds, with a mean inter-stimulus interval (ISI) of 5 seconds. During each flight evaluation, 39 letters were presented to the evaluation pilot. While the pilot performed his primary flying task, he also had to note each WAD letter and determine whether or not it was a member of the "positive" set of letters (called MSET) which was memorized prior to flight. The evaluation pilot responded to each letter by pulling the control stick trigger when a letter was "positive" (that is, a member of the memorized set) or depressing the upper stick button when the letter was "negative" (that is, not a member of the memorized set). As soon as a pilot responded, either correctly or incorrectly, the letter disappeared. If a response was not received within one second prior to the next ISI, a time-out error response was logged.

The pilot was instructed to respond to the WAD letters as quickly and accurately as possible; however, he was cautioned not to let his response to the WAD degrade his primary piloting tasks. Four different sizes of positive letter sets, containing zero (MSET0), one (MSET1), two (MSET2), and four (MSET4) letters were used to obtain a complete workload evaluation. The zero letter set was a baseline, since no letters were presented and the pilots had to only perform their primary task.

4. PERIPHERAL VISION DISPLAY

The PVD was manufactured by Garrett Manufacturing Ltd. for the Canadian Forces. The display provided a large horizon line which allowed the pilot to maintain aircraft attitude without looking directly at his gyro reference. The PVD horizon line was produced by a Helium-Neon laser which swept rapidly across the instrument panel. This line remained parallel with the outside horizon through 360 degrees of aircraft roll. The line also moved in pitch to reflect aircraft pitch attitude changes. A switch was available to the evaluation pilot which allowed selection of 1:1, 1:2, or 1:3 pitch scaling of the PVD line with respect to true pitch attitude. During this workload study, the 1:3 pitch scale was used which made the PVD horizon line one third as sensitive as the real horizon to aircraft pitch changes.

Other controls available to the evaluation pilot included a roll trim and pitch trim adjustment, a brightness control, and an on/off switch. The evaluation pilot switches were located on a remote control unit attached to the front cockpit left canopy rail. Other system components included a processor unit located above the safety pilot's instrument panel, and a laser projector located above and behind the evaluation pilot's right shoulder. Details concerning implementation of the PVD in the NT-33A aircraft are presented in References 3 and 4.

During daylight conditions, the ambient cockpit lighting was so bright that the PVD laser line could barely be seen. To overcome this implementation limitation, the cockpit was darkened using the instrument hood so that the PVD horizon could be seen easily under bright daylight conditions. With the instrument hood installed the evaluation pilots adjusted the PVD brightness to a middle range and thus had freedom to vary the laser intensity in either direction as ambient light conditions changed.

5. INSTRUMENTATION

The 28-channel NT-33A digital tape recorder recorded pilot control forces and displacement; aircraft response variables such as angles, angular rates, accelerations, and altitude; as well as WAD response times. The list of variables which were recorded during the PVD evaluation is included as Appendix A. A voice tape recorder was used to record pilot comments following each run. The Workload Assessment Device recorded the evaluation pilot's responses to the visual letters as well as his reaction times on a self contained cassette recorder.

Section III
TEST PROCEDURE

1. GENERAL

A total of nine NT-33A flights were flown at Edwards AFB from 28 to 31 March 1983 to collect PVD workload data for two evaluation pilots. These flights consisted of four flights for one evaluation pilot and five flights for the other pilot. Each pilot received two familiarization (FAM) flights and two data collection flights. Because of a malfunction of the PVD during Flight 4, evaluation pilot B received a third data collection flight. The FAM flights provided the pilots with experience using the PVD, performing the instrument task, and responding to the WAD secondary task. The data collection flights were used to collect comparative data on primary and secondary task performance with and without the PVD present. A breakdown of the nine NT-33A flights is shown in Table 2.

Table 2
NT-33A PVD EVALUATION FLIGHTS

PVD Flight Number	NT-33 Flight Number	Date	Flight Duration (hours)	Evaluation Pilot	Mission Type
1	3078	28 MAR 83	1.3	A	FAM 1
2	3079	28 MAR 83	1.3	B	FAM 1
3	3080	28 MAR 83	1.1	A	FAM 2
4	3081	29 MAR 83	1.4	B	FAM 2
5	3082	29 MAR 83	1.3	A	DATA 1
6	3083	29 MAR 83	1.2	B	DATA 1
7	3084	30 MAR 83	1.4	B	DATA 2
8	3085	30 MAR 83	1.2	A	DATA 2
9	3086	31 MAR 83	1.3	B	DATA 3
			11.5		

The evaluation pilots were two flight instructors from the Air Force Test Pilot School. Their flight experience and instrument times are shown in Table 3. The NT-33A safety pilot and in-flight experimenter was a Calspan engineering pilot. Because of the restricted visibility from the NT-33A with the instrument hood installed, all the NT-33A flights were monitored by a T-38 or F-4 chase aircraft. The chase aircraft and crew were provided by the Air Force Test Pilot School.

Table 3

EVALUATION PILOT BACKGROUND

Pilot A	Total time: 2300 hours Instrument: 600 hours Primary aircraft flown: RF-4, F-4
Pilot B	Total time: 4700 hours Instrument: 500 hours Primary aircraft flown: C-141, T-38

2. PVD PROCEDURES

After becoming airborne in the NT-33A, the evaluation pilot installed the instrument hood, turned on the PVD, adjusted the laser horizon trim, pitch ratio, and brightness. The horizon was trimmed in roll to correspond to the attitude gyro. The pitch trim was adjusted so that the horizon line was projected just below the attitude indicator and the pitch scale was checked to ensure that the 1:3 scale was selected. The evaluation pilots were instructed to adjust the brightness of the laser horizon so that they could discern the line in their peripheral vision, without being distracted by the brightness. The pilots were told to rely on the PVD for peripheral cues regarding deviations from a set aircraft attitude. The standard gyro indicator was to be used to initially establish the desired attitude and to check attitude when a deviation occurred. During the familiarization flights, the PVD was kept on for the duration of the flight to provide maximum exposure of the display to the pilots. During the data collection flights, the PVD was turned off or on according to the preset test sequence.

3. WAD PROCEDURES

The WAD secondary task had four levels of difficulty: MSET0, MSET1, MSET2, and MSET4. In the MSET0 condition no letters were presented on the WAD LCD. therefore, the evaluation pilot could devote his full attention to the instrument flying task. In the MSET1, MSET2, and MSET4 conditions, a sequence of letters were presented to the pilot at random intervals on the WAD LCD display. The pilot was instructed to watch the WAD display as much as possible without degrading his instrument task performance. As a letter appeared on the WAD display the pilot determined whether the letter was a member of that run's MSET. He then answered 'yes' for positive

MSET members by squeezing the trigger located on the center stick controller, or answered 'no' for non-members of the MSET by depressing the upper button of the control stick. The three sets of positive and negative letters used throughout this experiment are shown in Table 4.

Prior to each flight, a baseline set of secondary task reaction times was collected. This collection was completed in the aircraft just prior to engine start with the pilot in full flight gear. The instrument hood was installed to preclude pilot distraction and a set of three WAD runs, MSETS 1, 2, and 4, was completed. The pilot had no other task to perform and was told to watch the WAD display continuously in order to provide the fastest possible reaction times. Once airborne, the evaluation pilot performed the four WAD MSET tasks along with the instrument task in the order specified on the flight cards.

Table 4
LIST OF POSITIVE AND NEGATIVE LETTER SETS
FOR THE STERNBERG TASK

MSET	POSITIVE	NEGATIVE
1	A	B C F G H I M N P Q T U V X Y Z
2	JR	D E F G H I N Q T U X Y Z
4	KLSW	B C F G H I N P Q T U X Y Z

4. <u>INSTRUMENT PROCEDURES</u>

The instrument task performed by the pilot was to maintain a constant speed and altitude. During the first minute of the task angle of bank was held at zero. During the second and third minutes a constant 30 degree angle of bank was flown with a roll reversal at the two minute mark. The direction of the first turn was specified by the safety pilot based on other air traffic in the area and position considerations. The last portion of the instrument task was again flown at zero angle of bank. The instrument task was discontinued during the final segment when the WAD secondary task was complete. Each PVD evaluation run therefore consisted of a simple instrument maneuvering task with a duration of three to four minutes.

5. FLIGHT SEQUENCE

Each NT-33A flight contained eight consecutive runs. Each run was a unique combination of one of the four MSET levels and one of the two PVD conditions: present or absent. Following each run, the evaluation pilot commented on any distractions which occurred during that run as well as his impressions concerning use of the PVD and his performance. Appendix B contains a flight log documenting significant events and comments during the nine PVD flights.

The FAM flights provided an opportunity to fine tune the experiment prior to the data collection flights. During the first NT-33A flight at Edwards AFB it was found that the instrument hood did not darken the cockpit sufficiently to allow the pilots to easily see the laser horizon, even at its full bright setting. The hood was consequently darkened in order to lower the ambient lighting in the cockpit. Minor changes were also made to the variable stability gains in order to adjust the aircraft dynamics as fuel load changed. The most significant event which occurred during the FAM flights was that the PVD failed early during pilot B's second flight. This flight was continued in order to provide pilot B further experience in the NT-33A aircraft. As a consequence of the equipment failure, however, pilot B received less exposure to using the PVD than pilot A did.

No equipment malfunctions occurred during the data collection flights and no changes were made to the experiment design. The order of the evaluations performed on these data flights is shown in Table 5. Pilot A received two data flights. Because pilot B did not receive as much time using the PVD during the FAM flights he received a third data flight.

Table 5

EVALUATION SEQUENCE USED DURING PVD DATA FLIGHTS

DATA FLIGHT	RUN NUMBER	PVD STATUS	MSET CONDITION
1	1	ON	0
	2	ON	1
	3	ON	2
	4	ON	4
	5	OFF	0
	6	OFF	1
	7	OFF	2
	8	OFF	4
2	1	OFF	0
	2	OFF	4
	3	OFF	2
	4	OFF	1
	5	ON	0
	6	ON	4
	7	ON	2
	8	ON	1
3 (Pilot B only)	1	ON	0
	2	ON	2
	3	ON	1
	4	ON	4
	5	OFF	0
	6	OFF	2
	7	OFF	1
	8	OFF	4

Section IV
DATA ANALYSIS

1. GENERAL

Following the nine NT-33A flights of the PVD, the data collected in flight were reviewed to determine if any trends concerning use of the device were evident. Due to the small sample size (two evaluation pilots), descriptive rather than inferential statistics were employed. Three effects were of interest:

1) Effect of the PVD on secondary task (WAD) performance and on angle of bank accuracy.
2) Effect of performing the secondary task on primary task performance.
3) Effect of extended exposure (learning) to the PVD.

Strip chart recordings were made from the digital flight tapes showing NT-33A angle of bank, airspeed, and altitude as well as the timing of WAD letter presentations and the pilots' reaction times in responding to the letters. The voice recordings of pilot comments were reviewed to eliminate flight segments during which pilot distractions occurred as well as to obtain pilot opinions concerning utility of the display.

Three performance measures (bank angle error, altitude, and airspeed) were read from the flight records at one second intervals. The pilot's response times to the WAD letters as well as whether the response was correct or incorrect was obtained directly from the WAD data recording system. Data points for flight performance as well as letter response were not used for segments of each flight evaluation when the pilot was transitioning from one angle of bank to another or when the pilot was distracted. Data points which were greater than three standard deviations from the mean were also discarded. This was found to occur only for bank angle error. Based on previous research (Reference 5) reaction times to the WAD secondary task were used only for correct responses. After removal of the above segments, the data from each evaluation typically consisted of 150 seconds of flight record. Of the eight flight evaluations performed on each of the five data flights, three records were incomplete due to data recorder malfunctions. These records contained the PVD off/MSET2 evaluation on pilot B's first data flight, which resulted in no usable data; and the PVD on/MSET's 0 and 4 records on pilot B's third data flight, which provided only about 50 seconds of usable data.

Because the PVD malfunctioned during evaluation pilot B's second FAM flight he received less exposure to using the PVD in flight. For that reason, only data from evaluation pilot B's fourth and fifth flights were used in the following analysis, while data from pilot A's third and fourth flights were used.

2. EFFECT OF THE PVD

The effect of the PVD on pilot workload was assessed from the secondary task data. Linear regression lines for each evaluation pilot plotted as a function of reaction time and MSET size are presented in Figures 4 and 5, respectively. The baseline data presented in these figures consist of the WAD reaction times obtained in the NT-33A on the ground prior to flight. The corresponding slopes and intercepts for each pilot are presented in Tables 6 and 7.

Table 6
LINEAR REGRESSION SLOPES AND INTERCEPTS
FOR EVALUATION PILOT A

Linear Regression	Baseline (msecs)	PVD Off	PVD On
Slope	17	-21	-19
Intercept	520	1120	950

Table 7
LINEAR REGRESSION SLOPES AND INTERCEPTS
FOR EVALUATION PILOT B

Linear Regression	Baseline (msecs)	PVD Off	PVD On
Slope	28	31	79
Intercept	450	870	740

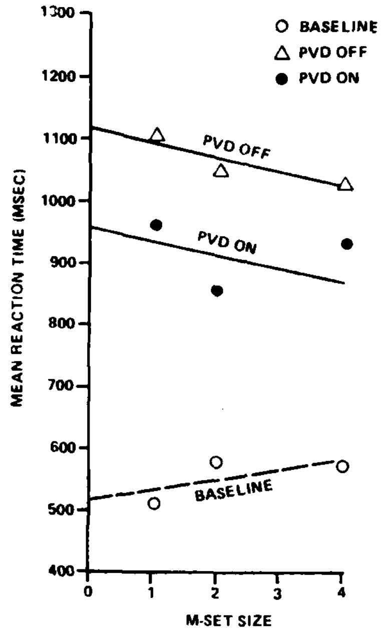

Figure 4 LINEAR REGRESSION LINES FOR EVALUATION PILOT A PLOTTED AS A FUNCTION OF REACTION TIME AND MEMORY SET SIZE FOR FLIGHT AND BASELINE CONDITIONS

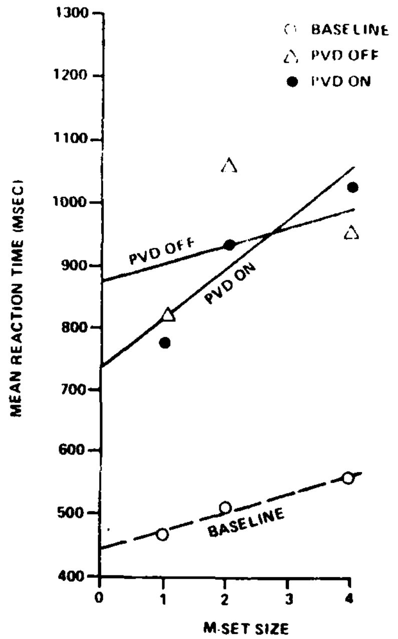

Figure 5 LINEAR REGRESSION LINES FOR EVALUATION PILOT B PLOTTED AS A FUNCTION OF REACTION TIME AND MEMORY SET SIZE FOR FLIGHT AND BASELINE CONDITIONS

Both plots of baseline reaction times, obtained on the ground, show positive slopes and are fairly linear with increasing MSET size. The relatively long reaction times, in the order of 500-600 milliseconds, can be attributed to flight equipment encumbrances and to the somewhat awkward position of the WAD display.

The airborne workload data collected from pilot A with both the PVD on and off produced the negative slopes in Figure 4. The negative slopes, which indicate faster reaction times as MSET size increased, could have resulted from the pilot altering his technique of coping with the WAD task with changing MSETs. However, Figure 4 also shows that the mean reaction time for each MSET is consistently 100-200 msecs faster with the PVD turned on than with it off. In order to achieve fast reaction times as WAD letters appeared at random time intervals, the pilots had to look at the WAD display as often as possible to see a letter when it first appeared. In this regard, Figure 4 indicates that pilot A was more successful in watching the WAD display when the PVD was turned on. This is supported by pilot A's comments during PVD Flights 5 and 8 contained in Appendix B. Pilot A commented several times that with the PVD turned on, he could stare at the WAD display; while with the PVD off, he was required to scan the flight instruments more often.

The airborne Sternberg task data collected on pilot B (Figure 5) show a fairly linear MSET relationship with positive slope for the PVD on case. The PVD off flight data is more scattered. Mean reaction times for the WAD task for MSET1 and MSET2 are shorter with the PVD turned on, and the mean WAD reaction time for MSET4 is shorter with the PVD off. Part of the inconsistency of pilot B's data could be due to his changing instrument scan technique as he experimented with different strategies to accommodate the WAD and utilize the PVD. For example, on PVD Flight 7 pilot B stated that he was noticing more PVD roll cues but was concerned with the lack of pitch cues. On PVD Flight 9 he was beginning to use the PVD even more for roll cues and could look at the WAD, waiting for letters to appear (Appendix B). Another factor mentioned in the pilot's comments which may have contributed to flight data scatter for pilot B, was the presence of occasional sunlight on the instrument panel. Pilot B's last two data flights were flown in the early morning (0800 takeoff). With the sun near the horizon it was easier for beams of sunlight to shine past the evaluation pilot's front cockpit hood and onto his instrument panel.

One of the purposes of the PVD addressed by this study was to aid the pilot in maintaining a desired aircraft attitude while he directs his attention to aircraft systems other than flight instruments. To determine whether aircraft attitude control suffered when the PVD was used, each evaluation pilot's mean deviation from assigned bank angle as well as an estimate of the standard deviation around the mean were calculated for PVD on and PVD off. The results are shown in Table 8. The estimate of the standard deviation was derived using a weighted average of the standard deviations of each pilot's flight records. The weights used were the number of data points over which each standard deviation was computed. Because of the high variability in the data, it was decided to discard values beyond three standard deviations of the mean. This occurred only for the estimate of standard deviation of bank angle error.

Table 8

MEAN AND ESTIMATE OF STANDARD DEVIATION OF BANK ANGLE ERROR

Evaluation Pilot	PVD			
	ON		OFF	
	ϕ_e	σ estimate	ϕ_e	σ estimate
A	0.8°	1.5	0.5°	1.5
B	0.6°	1.7	0.5°	1.5

Examination of Table 8 suggests that both evaluation pilots were able to maintain their assigned bank angles with slightly greater precision when they used the attitude gyro instead of PVD derived peripheral cues.

3. EFFECT OF THE SECONDARY TASK ON PRIMARY TASK PERFORMANCE

Although each evaluation pilot was instructed not to degrade primary task performance (flight control) in order to perform the secondary task (Sternberg task), this tradeoff may have occurred. To test for this possibility, the means and standard deviations of the three measures of flight performance were calculated for each of the four MSETs (0, 1, 2, and 4). The mean values for each pilot's three primary task performance measures were examined and did not seem to indicate a differential effect due to the PVD presence or absence. The standard deviations of these performance measures were felt to be more sensitive since they reflect the degree to which the pilot could maintain a constant flight condition throughout the primary instrument task. The standard deviations of bank angle error, airspeed, and altitude for pilots A and B with PVD on and off are shown in Figures 6 through 8.

In general, no compelling trends of primary/secondary task tradeoff are evidenced in these plots. There may be one exception - consistency of evaluation pilot B's altitude maintenance with the PVD on. For the more difficult WAD tasks (MSETS 2 and 4) pilot B may have devoted less attention to maintaining a constant altitude in order to watch the WAD display more closely. In his flight comments, pilot B felt this was the case. He stated that as he relied more on peripheral attitude cues from the PVD he felt his pitch control was degraded (Appendix B). Any degradation in aircraft longitudinal control when using the PVD cannot be viewed as conclusive since the least sensitive PVD pitch scaling was used during this experiment.

4. EFFECT OF LEARNING

For highly practiced pilots the addition of a new flight display in the cockpit is often associated with a period of adjustment as the pilot learns new ways to use this display. For the PVD, the learning would be evidenced in the precision of angle of bank control and in the associated workload. For each evaluat n pilot, the mean reaction time of correct responses to the Sternberg task and the estimated standard deviation around mean bank for his last three flights using the PVD are plotted in Figures 9 through 12.

As indicated in Figures 9 and 10, there was a general decrease in reaction time for correct responses to the Sternberg task. This was especially evident for evaluation pilot A. This decrease occurred both when the PVD was present and absent suggesting that the evaluation pilots were becoming more proficient at the Sternberg Task throughout the entire experiment. Even though only data from the last two flights were used in the earlier analysis, the slight learning trend which was still evident during these flights may have made the data less consistent.

Mean deviation from the assigned bank angle seems to have remained constant over the course of the study (see Figures 11 and 12). This was not unexpected since maintaining bank angle is a highly practiced flight task. Although evaluation pilot A showed a general downward trend in variance in angle of bank control over the course of the experiment, evaluation pilot B showed the trend in his first and second data flight but not his last data flight. It was during the last flight that the greatest variability in his flight performance occurred. It was also during this flight that pilot B reported the most increased use of the PVD.

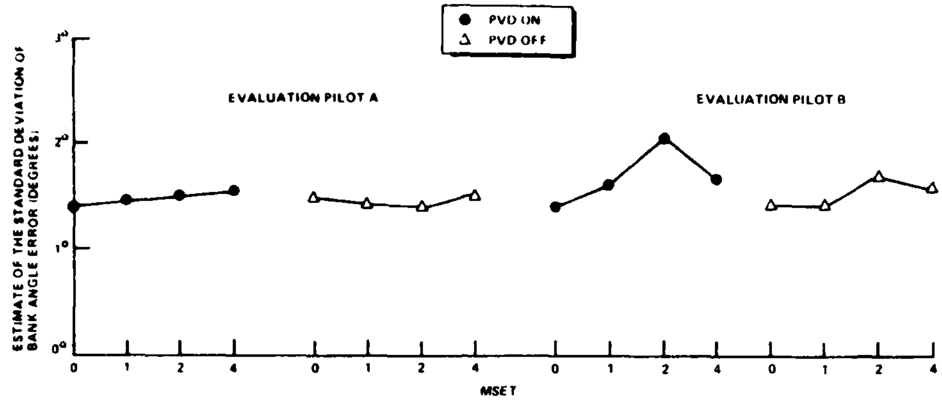

Figure 6 ESTIMATED STANDARD DEVIATION OF BANK ANGLE ERROR AS A FUNCTION OF MSET SIZE AND PVD PRESENCE OR ABSENCE

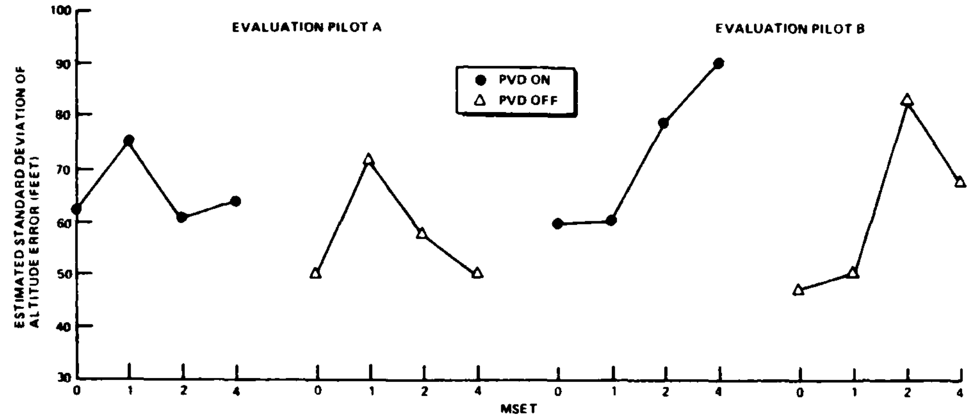

Figure 7 ESTIMATED STANDARD DEVIATION OF ALTITUDE ERROR AS A FUNCTION OF MSET SIZE AND PVD PRESENCE OR ABSENCE

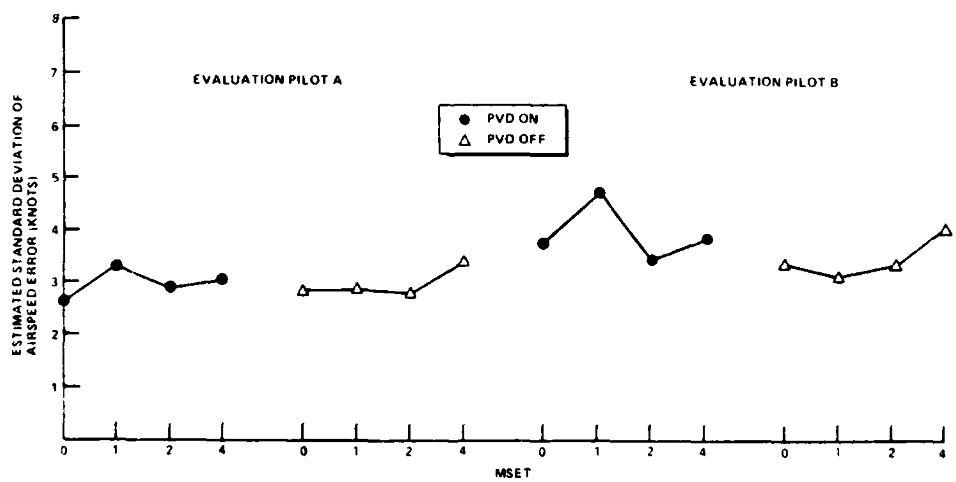

Figure 8 ESTIMATED STANDARD DEVIATION OF THE AIRSPEED ERROR AS A FUNCTION OF MSET SIZE AND PVD PRESENCE OR ABSENCE

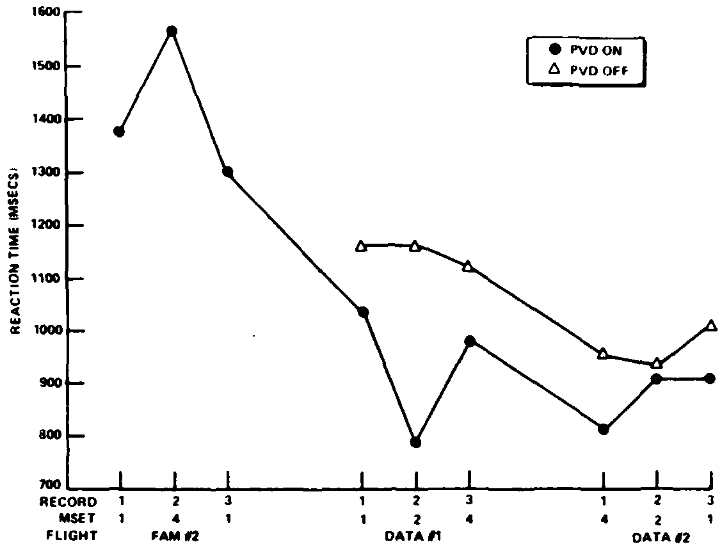

Figure 9 MEAN REACTION TIME FOR CORRECT RESPONSES TO THE STERNBERG TASK FOR EVALUATION PILOT A (NOTE: DURING THE FAM FLIGHTS THE PVD WAS ALWAYS ON)

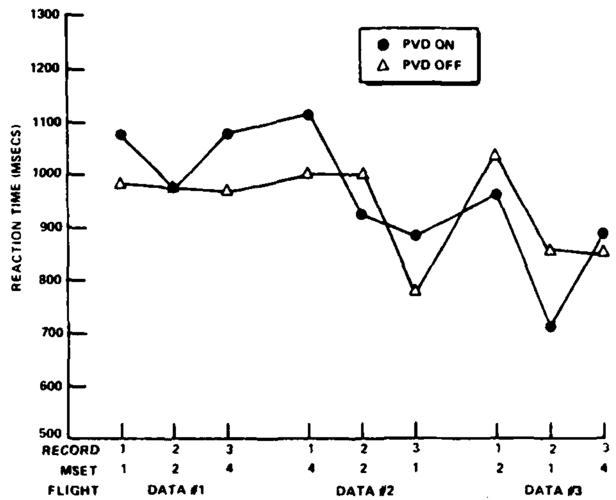

Figure 10 MEAN REACTION TIME FOR CORRECT RESPONSES TO THE STERNBERG TASK FOR EVALUATION PILOT B

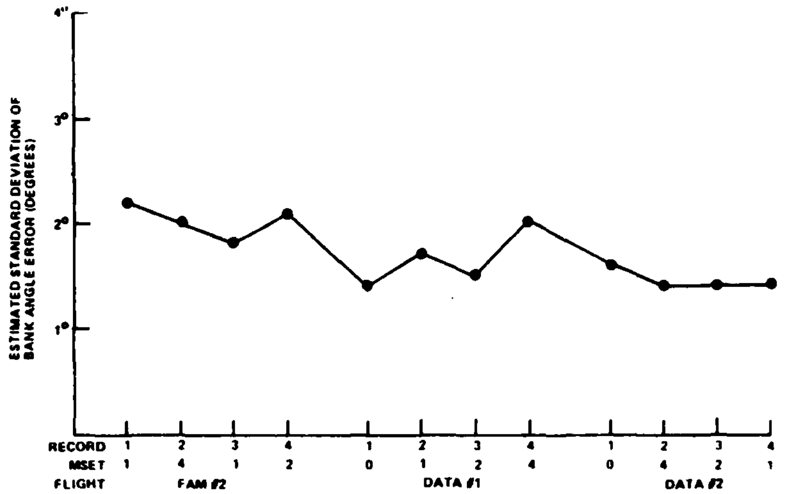

Figure 11 ESTIMATED STANDARD DEVIATION OF BANK ANGLE ERROR (PVD ON) FOR EVALUATION PILOT A

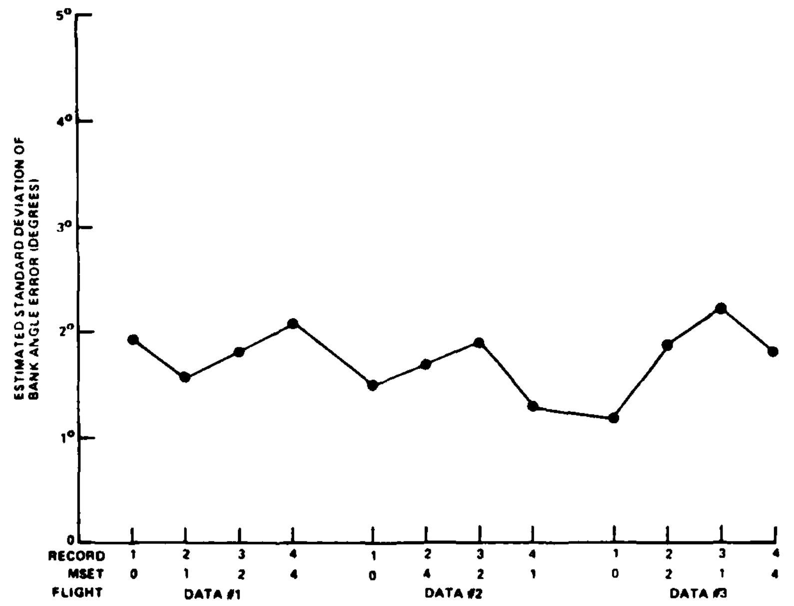

Figure 12 ESTIMATED STANDARD DEVIATION OF BANK ANGLE ERROR (PVD ON) FOR EVALUATION PILOT B

Section V
FINDINGS

It must be stressed that no conclusions regarding the utility of the PVD as a device to reduce pilot workload can be made based on the results of nine flights and two evaluation pilots. A summary of the findings of this study are now provided.

1. Presence of the Peripheral Vision Display reduced the WAD reaction times of one of the subject pilots. The reaction times of the other pilot showed mixed results.

2. Both evaluation pilots felt the PVD allowed them to devote more attention to watching the WAD display.

3. The two pilots in this study adapted to the PVD at significantly different rates. Pilot A began using the peripheral information on his second flight; pilot B did not find the display of significant value until his fifth flight.

4. The PVD laser horizon must be brighter in order to be easily seen in daylight.

5. Performance of the Sternberg task continued to improve with practice as the flight program progressed.

6. Because of the lengthy learning period required for the PVD as well as the WAD, future evaluation pilots should receive many hours of practice in using these devices prior to the collection of comparative data. It is recommended that future airborne PVD studies accomplish this training in a ground simulator prior to in-flight verification.

7. During the application of the Sternberg task to an airborne evaluation, evaluation pilots may modify their response techniques to exhibit negative reaction time/MSET slopes. These subjects should be identified early-on

and receive further training in the secondary task in a less expensive environment before continuing the flight experiment.

8. In the event further evaluation of the PVD is flown in the NT-33A, the aft section of the NT-33A instrument hood should be modified to preclude pilot distraction due to intermittant sunlight intrusion.

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2. Hall, G.W. and Huber, R.W., "System Description and Performance Data for the USAF/Calspan Variable Stability T-33 Airplane," Calspan Report No. BM-2821-F-2, July 1970.

3. Huber, R.W., "Class II Modification Documentation for Malcolm Horizon Peripheral Vision Horizon Device, Part I," T-33 Technical Memo No. 197, October 1981.

4. Huber, R.W., "Class II Modification Documentation for Malcolm Horizon Peripheral Vision Horizon Device, Part II," T-33 Technical Memo No. 213, September 1982.

5. Schiflett, S. G., "Evaluation of a pilot workload assessment device to test alternate display formats and control handling qualities," NATC-SY-33R-80, July 1980.

Appendix A

DIGITAL TAPE RECORDING LIST

Digital Channel Number	Variable	Description	Scale Factor (x Per Volt)
1	h_p	Altitude	-1300 ft (720 ft. = 8.45V)
2	N_z	Normal Acceleration	+.50 g
3	V_i	Indicated Airspeed	-27.5 kt (0 kt = +10V)
4	q	Pitch Rate	+5.0°/s
5	$\sin \theta$	Pitch Angle	+5.88°
6	r	Yaw Rate	+5.00°/s
7	$\delta_{ES_{cs}}$	Long Stick Deflection	-1.0 in
8	v	Sideslip	+2.0°
9	TTL	WAD Letters	5V = letter displayed
10	δ_{AS}	Lateral Stick Deflection	-1.0 in
11	-	(Not Used)	
12	p	Roll Rate	+10.0°/s
13	ϕ	Roll Angle	+10.0
14	$\delta_{e_{com}}$	Elevator Command	-2.0 deg
15	-	(Not Used)	
16	δ_e	Elevator Deflection	+2.56°
17	N_y	Lateral Acceleration	-.049 g
18	F_{ES}	Longitudinal Stick Force	+20.0 lb
19	-	(Not Used)	
20	δ_r	Rudder Deflection	+4.92°
21	δ_{a_T}	Aileron Deflection	+3.90°

Appendix A

DIGITAL TAPE RECORDING LIST (Continued)

Digital Channel Number	Variable	Description	Scale Factor (x Per Volt)
22	-	(Not Used)	
23	δ_{AS}	Lateral Stick Deflection	-1.0 in
24	α_v	Angle of Attack	+2.00 deg
25	F_{AS}	Lateral Stick Force	+10.0 lb
26	δ_{RP}	Rudder Pedal Position	-.5 in
27	F_{RP}	Rudder Pedal Force	-10.0 lb
28	q_c	Dynamic Pressure	+.5 PSI

Appendix B
FLIGHT LOG

<u>PVD Flight 1</u>, Pilot A, FAM Flight 1, 28 MAR 83, T/O time 0920

Run 1, PVD ON, MSET0: Turbulence forces you to monitor instruments all the time. PVD is within peripheral field of view. Was sometimes hard to pick up dots (of PVD). Had problem watching clock with other instruments.

Run 2, PVD ON, MSET1: Get more problem with pitch than roll because of (artificial) turbulence.

Run 3, PVD ON, MSET2: Task seems to be getting easier.

Run 4, PVD ON, MSET4: Laser is not quite bright enough to catch attention.

Run 5, PVD ON, MSET1: (no comment)

Run 6, PVD ON, MSET4: (no comment)

Run 7, PVD ON, MSET2: Still having problems with clock scan.

(After Flight 1, the instrument hood was darkened.)

<u>PVD Flight 2</u>, Pilot B, FAM Flight 1, 28 MAR 83, T/O time 1300

Run 1, PVD ON, MSET0: Pitch turbulence was the most distracting. Spent most of the time working on altitude control. Don't feel roll turbulence as much -- but it is there. Another distracting thing is that attitude indicator precesses in turns. PVD brightness is fine. PVD location below attitude indicator looks nice.

Run 2, PVD ON, MSET1: About half way through run PVD went off -- recycled it and it came on again; this happened once more later. Turbulence in pitch again most disturbing. This was first run with WAD -- am using it like another item in the crosscheck. Didn't notice the PVD at all this time.

Run 3, PVD ON, MSET2: Felt like I was spending less time looking at WAD. A couple times in left turn when PVD line was on altimeter, I did use it for roll cues. Am not using it consciously at all for pitch cues.

Run 4, PVD ON, MSET4: Did notice roll turbulence this time. I think I was using red line for roll before I looked at attitude indicator. I find once I get stabilized I have time to look at WAD. When rolling and getting set up I don't have time to pay attention (to WAD).

Run 5, PVD ON, MSET1: No new comments. Forced myself to look at WAD while rolling and could look down there a couple times.

Run 6, PVD ON, MSET4: Found pitch turbulence very distracting. Felt maxed out a couple times.

Run 7, PVD ON, MSET2: Toward end when I rolled wings level noticed PVD wasn't trimmed wings level. No trouble seeing PVD or WAD at all. Task difficulty — felt saturated a couple times. Is difficult enough. Haven't changed the way I use the PVD. The WAD alters my instrument scan. I look down and see a letter and wonder how many I missed, so I speed up scan.

<u>PVD Flight 3</u>, Pilot A, FAM Flight 2, 28 MAR 83, T/O time 1540

Run 1, PVD ON, MSET1: Darkened cockpit hood helped a lot in seeing PVD. Noticed a lot more small motions in attitude using the PVD.

Run 2, PVD ON, MSET4: Things going a lot smoother than this morning. Blinking PVD showed me I had a large pitch correction.

Run 3, PVD ON, MSET1: Reversed angle of bank 10 seconds late. Am noticing PVD information.

Run 4, PVD ON, MSET2: Got distracted by PVD halfway through and missed some letters.

Run 5, PVD ON, MSET4: Got some external turbulence at about the first minute. Used the PVD more. Kept eyes glued to WAD. At 3 minute mark got dark in cockpit. (Sun low on horizon and blanked by wing.)

Run 6, PVD ON, MSET2: Noticed PVD pitch more than this morning. During wings level portion can stare at WAD. Is harder to do this in turn.

Run 7, PVD ON, MSET1: Distraction due to climb and then altitude correction. Missed some letters.

PVD Flight 4, Pilot B, FAM Flight 2, 29 MAR 83, T/O time 0800

Run 1, PVD ON, MSET0: During middle of run PVD locked in roll and would not reset. Flight was continued to practice instrument task and WAD.

(After Flight 4, the 300 gallon VSS gain settings were modified slightly.)

PVD Flight 5, Pilot A, Data Flight 1, 29 MAR 83, T/O time 1200

Run 1, PVD ON, MSET0: Everything's normal. T-33 fuel was 630 gal.

Run 2, PVD ON, MSET1: More trouble seeing PVD today than yesterday. Will use a couple more clicks of brightness. Am able to stare at WAD more than yesterday, and am catching changes out of corner of eye.

Run 3, PVD ON, MSET2: Am catching peripheral cues from PVD. Now using roll more, and a little pitch.

Run 4, PVD ON, MSET4: At 3 minute mark when rolling wings level was able to stare at WAD while rolling. Crosschecked (attitude gyro) real quick. (PVD) was a definite aid. Got a large altitude deviation at 1 + 45 second point that distracted for about 30 seconds.

Run 5, PVD OFF, MSET0: Can handle task fairly well.

Run 6, PVD OFF, MSET1: Really had to increase the rate of my instrument crosscheck. Caught a lot more of the letters just as they were going out.

Run 7, PVD OFF, MSET2: (no comment).

Run 8, PVD OFF, MSET4: (Artificial turbulence to rudder turned to zero because of real turbulence). Workload really increased. Had to look at attitude indicator a lot. Every time I feel a bump have to look up and check my attitude. Then usually miss a letter. With PVD on I can tell what the bump has done and can wait to make a correction. (T-33 fuel was 400 gallons).

PVD Flight 6, Pilot B, Data Flight 1, 29 MAR 83, T/O time 1500

Run 1, PVD ON, MSET0: Spent most of time with the attitude indicator. Had few distractions. Only time noticed PVD was in left turns when it shown on altimeter. PVD brightness OK — using midrange. (T-33 fuel was 600 gallons).

Run 2, PVD ON, MSET1: Started to turn wrong way at end of first minute. On some headings in the middle of the first turn had trouble resolving letters on WAD. I know PVD is there but I'm not using it for pitch. I don't know if I'm using it for roll.

Run 3, PVD ON, MSET2: On some headings was hard to see WAD. This time I was aware of red line moving when I rolled.

Run 4, PVD ON, MSET4: A couple times while looking at WAD could see PVD at top of vision.

Run 5, PVD OFF, MSET0: Since WAD not there could spend time with attitude indicator. Was aware that PVD wasn't there.

Run 6, PVD OFF, MSET1: On one heading couldn't see WAD.

Run 7, PVD OFF, MSET2: More problems seeing WAD letters (due to sun low on horizon). (Digital record was turned on late).

Run 8, PVD OFF, MSET4: Early in run had trouble reading letters on WAD. Seems to be heading dependent. Happened again somewhere in second turn. (T-33 fuel was 370 gallons).

<u>PVD Flight 7</u>, Pilot B, Data Flight 2, 30 MAR 83, T/O time 0800

Run 1, PVD OFF, MSET0: Air smooth today - no natural turbulence. (T-33 fuel was 600 gallons).

Run 2, PVD OFF, MSET4: Distracted during first turn from sunlight moving across instrument panel. After roll out of first turn started to climb, so missed WAD for a while.

Run 3, PVD OFF, MSET2: During first minute had trouble seeing WAD on that heading.

Run 4, PVD OFF, MSET1: Had beam of sunlight on instrument panel during first turn. No problem seeing WAD. Got a case of 'leans'. Forgot to reverse turn on time.

Run 5, PVD ON, MSET0: Was getting roll cues from PVD. PVD drifted in attitude from the attitude gyro. Having PVD more left wing down (when wings level) is very bothersome. No problem seeing PVD.

Run 6, PVD ON, MSET4: PVD is more compelling roll indicator than attitude gyro. As I look up I can more accurately assess whether aircraft is moving in roll. I feel my pitch feel was degraded because I didn't come up to the attitude indicator as often.

Run 7, PVD ON, MSET2: Clock didn't start when I first hit it. About 40 seconds into first minute this caused distraction. Started clock again during first turn. Didn't seem to be a good run. There were times I was trying to figure out where PVD was, and didn't pay attention to WAD. No problems seeing PVD or WAD.

Run 8, PVD ON, MSET1: Felt comfortable with run. No problem seeing PVD or WAD. No pitch cues from PVD at all. I noticed more roll cues. I've changed my scan because I'm looking at WAD more, but this has made by altitude control worse. (T-33 fuel was 370 gallons).

PVD Flight 8, Pilot A, Data Flight 2, 30 MAR 83, T/O Time 1100

Run 1, PVD OFF, MSET0: All was normal. Some turbulence during the beginning which was distracting. (T-33 fuel was 650 gallons).

Run 2, PVD OFF, MSET4: Noticed a really increased crosscheck. Was trying to use peripheral cues for WAD, but would hit wrong response.

Run 3, PVD OFF, MSET2: Missed letters again because I was trying to answer WAD using peripheral cues. Got some airspeed deviations, and some WAD letter dropouts at about the 1 minute mark.

Run 4, PVD OFF, MSET1: I'm ok as long as airspeed and altitude deviations are small. When they get bigger I have to start watching the instruments.

Run 5, PVD ON, MSET0: This was a break. I could look around, check engine instruments. Much lighter workload.

Run 6, PVD ON, MSET4: Noticed an improvement in parameters and ability to stare at WAD. Caught all the bumps and small angle changes on the /D. Felt I was more relaxed, and it was easier to do task.

Run 7, PVD ON, MSET2: Two (altitude or airspeed) deviations in the middle of the run. Was probably using the scan rather than stare technique on the WAD.

Run 8, PVD ON, MSET1: Seemed like one of my best runs. Very easy to stare at WAD. (T-33 fuel was 400 gallons).

PVD Flight 9, Pilot B, Data Flight 3, 31 MAR 83, T/O time 0800

Run 1, PVD ON, MSET0: Was picking up roll cues from PVD, especially when looking at altimeter and line was on it. Was distracted by pitch precession of attitude indicator. (T-33 fuel was 600 gallons).

Run 2, PVD ON, MSET2: Was spending a lot of time looking at WAD with PVD up at the top of my vision. Saw bank angle changes which made me look back to attitude indicator. Changed my use of PVD - used it more for roll cues and spent more time on the WAD.

Run 3, PVD ON, MSET1: Was using PVD up at top of peripheral vision.

Run 4, PVD ON, MSET4: Was taking the luxury of watching WAD, waiting for letters to come up, but have perception that flying suffers.

Run 5, PVD OFF, MSET0: Only distraction was a little bit of gyro precession.

Run 6, PVD OFF, MSET2: Very little natural turbulence during the whole flight. It seems that I don't get attitude information as quickly out of the attitude indicator. Scan was different than with PVD on - had to make my eyes go from attitude indicator to WAD. Didn't see as many letters appear.

Run 7, PVD OFF, MSET1: No distractions. Had to actively make my scan go from attitude indicator to WAD. Really working hard at that. Felt that pitch control was better than with PVD ON.

Run 8, PVD OFF, MSET4: During turns was hard to perceive letters from WAD. Forgot the first turn. Felt slow and maxed out a couple times. (T-33 fuel was 390 gallons).

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